CHINESE JOURNAL OF PHYSICS VOL. 37, NO. 2 APRIL 1999

Atomic Imaging of Graphite Surface Using Ambient Scanning Tunneling Microscope

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(Received October 9, 1998)

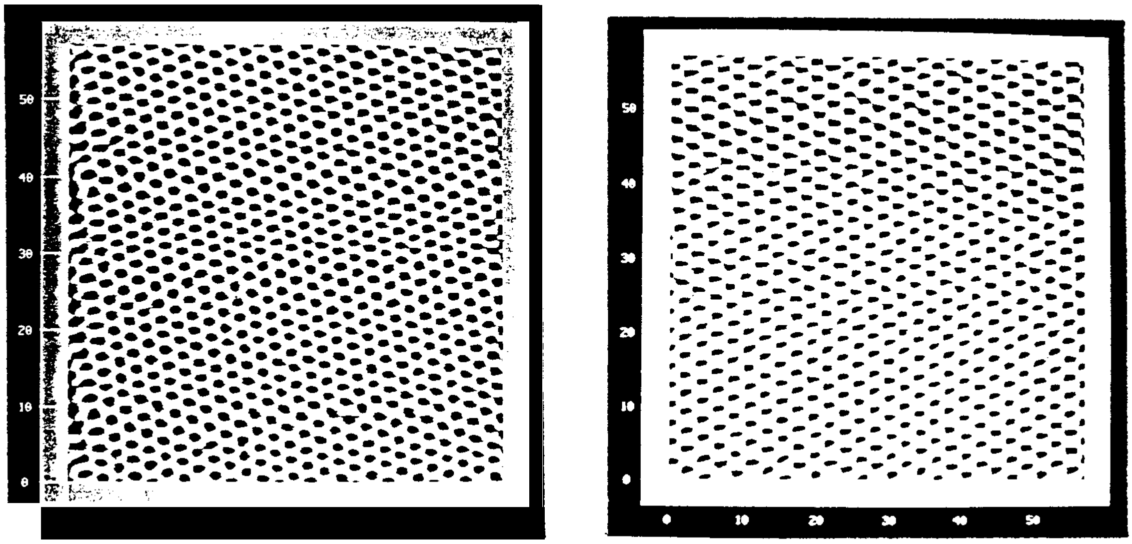
The true hexagonal atomic structure of a graphite surface has been imaged by the Scanning Tunneling Microscope in air. The electropolished tungsten tips used in these experiments were a few microns in tip curvature diameter. These results demonstrate the inadequacy of a theoretical model for graphite surface electronic state structure.

PACS. 61.16.Ch – Scanning probe microscopy : scanning tunneling, atomic force, scanning optical, magnetic force, etc.
PACS. 68.35.Bs – Surface structure and topography.

I. Introduction

After the invention of the Scanning Tunneling Microscope (STM) [I], there have been broad applications in surface science for atomic-scale imaging of different materials [2]. STM is a powerful tool for studying surface structure at atomic resolution in ultrahigh vacuum (UHV). For oxidation resistive materials, STM can also be used to obtain images of atoms in air or under mineral oil. The atomic images reveal the surface structures of these conductive materials and are consistent with what is known from chemistry and physics. An STM image, obtained either from constant height mode or constant current mode, is equivalent to the topography of the electronic state of the material surface in most cases. Some STM images show the electronic effects on the material surface and form different patterns instead of real topography. The well-known monolayer hexagonal ring structure of highly oriented pyrolytic graphite (HOPG) forms a trigonal pattern of atoms when it is imaged by STM in UHV or air. This phenomenon of highly asymmetric atomic structure was interpreted by Tomnek and Louie [3] as a purely electronic effect for bias voltages below 1 V. The trigonal atomic structure in graphite images is used as an experimental standard in the calibration of the instrument and its performance evaluation [4].

The development of atomic force microscopy (AFM) [5] also has achieved atomic resolution in UHV [6]. The filtered AFM images of a graphite surface show a clear hexagonal ring structure [7]. It seems that the AFM is more reliable than the STM in obtaining topographic atomic images. Nevertheless, it is important to know that an STM image of a graphite surface can differ from the theoretical model. The electronic effects do not always occur. In this paper, atomic imaging of a graphite surface using ambient STM demonstrates that this technique is still useful for topographical studies even in air.



(a) (b)

FIG. I. The STM images of graphite surface at atomic resolution. The horizontal length of each image in 57Å. Images were scanned at 20 Hz using constant height mode. The tungsten tip bias voltage was set at +0.5 V. The tunneling current were set at 4.6 nA in (a) and 10 nA in (b).

II. Experiment and results

In Fig. 1, two patterns of a graphite surface are shown. The horizontal length of each image is 57Å. Fig. 1(a) shows a hexagonal ring structure of graphite topography. The tungsten tip bias voltage was +0.5 V, and the tunneling current was 4.6 nA. The image was obtained at constant height mode and scanned at 20 Hz. Since the bias voltage was below 1 V and the image clearly reveals hexagonal structure, this result differs from the theoretical model. Fig. l(b) shows the trigonal atomic arrangement, an asymmetric pattern interpreted as a purely electronic effect. The tip bias voltage was $0.5 V, and the tunneling current was 10 nA. The image was scanned at 20 Hz using constant height mode. Both images are obtained with the same tip and HOPG. The tunneling current at 4.6 nA is not a critical condition in order to obtain a honeycomb topographic image. Fig. 2 shows another STM image of the HOPG surface of a smaller area, 25Å x 36Å. The tip bias voltage was +0.5 V and the tunneling current was 10 nA. Although scanning conditions were the same as for Fig. l(b), the hexagonal structure was reproduciblely obtained. Careful investigation of the image shows that the hexagonal ring is very even in the upper-left region, and it becomes somewhat asymmetric in the lower-right region. Since the STM image is dependent on the interaction between the tip and the sample, this difference may be due to tip structure or another electronic effect on the sample.

It is interesting to know that the electropolished tungsten tips used in these experiments were a few microns in tip curvature diameter. When tungsten tips were electropol-

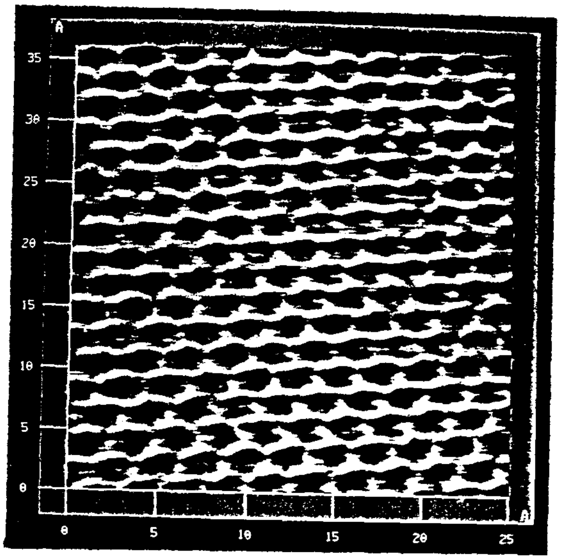


FIG. 2. The STM image of graphite surface in smaller scanning area. The image size is 25Å×36Å. Although operating conditions were the same as for Fig. l(b), the tungsten tip was replaced and HOPG was freshly cleaved again.

ished to be very thin and sharp at the submicron tip curvature, it was difficult to obtain any clear image of areas smaller than 50Å x 50Å at 20 Hz scanning rate. Operating the STM in air at a slow scanning rate did not produce better images.

In conclusion, a hexagonal atomic structure graphite surface can be imaged by STM in air. This result differs from the predictions of a theoretical model.

Acknowledgement

The support and encouragement by Dr. John D. Baldeschwieler at the Califronia Institute of Technology is gratefully acknowledged.

References

[1] G. Binnig and H. Rohrer, Rev. Mod. Phys. 59, 615 (1987).
[2] C. J. Chen, *Introduction* to Scanning *Tunneling* Microscopy, (Oxford University Press, New York, 1993).
[3] D. Tomnek and S. G. Louie, Phys. Rev. B37, 8327 (1988).
[4] L. A. Hockett and S. E. Creager, Rev. Sci. Instrum. 64, 263 (1993).
[5] D. Rugar and P. Hansma, Phys. Today 43, 23 (1990).
[6] F. J. Giessibl, Science 267, 68 (1995).
[7] S. A. C. Gould, K. Burke and P. K. Hansma, Phys. Rev. B40, 5363 (1989).